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SUBJECT: Disposal of Spent S-IVB Stage  
on Hybrid Missions - Case 310

DATE: March 17, 1969

FROM: L. P. Gieseler

ABSTRACT

In a previous study (Reference 1) the safe disposal of the S-IVB through cold propellant dumps was discussed for nominal free return Apollo Lunar missions. This memorandum extends the results to hybrid missions. These missions are characterized by an initial free return trajectory having a greatly increased periselene altitude. The spent S-IVB, in the absence of a corrective thrust, will follow this trajectory.

It is concluded that the minimum velocity impulse required to place the S-IVB in a slingshot orbit is relatively insensitive to the periselene altitude of the free return trajectory. However, the range of velocity impulses which will produce a slingshot trajectory is significantly reduced as the periselene altitude is increased. This effect places greater accuracy requirements on the method of slingshot implementation for hybrid translunar trajectories. In addition the probability of an earth impact by the spent S-IVB stage is also potentially increased because of the increased sensitivity of perigee to the magnitude of the dump impulse.

(NASA-CR-106439) DISPOSAL OF SPENT S-4B  
STAGE ON HYBRID MISSIONS (Bellcomm, Inc.)

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MEMORANDUM FOR FILE

I. INTRODUCTION

The safe disposal of the spent S-IVB after translunar injection (TLI) was discussed in Reference 1. The velocity impulse required to place the S-IVB in a slingshot orbit was calculated under various conditions, and it was shown that the required impulse can be produced by dumping unburned propellant through the S-IVB engine. For this work an Apollo mission having a free return trajectory with a near 60 n.mi. periselene altitude was assumed.

This memorandum extends the results to hybrid missions. In these missions the space vehicle is initially injected into a free return trajectory having a greatly increased periselene altitude. After a specified time has elapsed, the spacecraft then transfers to a non-free return trajectory having a periselene altitude near 60 n.mi. In the absence of a corrective thrust, the spent S-IVB will proceed along the original high periselene free return trajectory. Additional information about the characteristics and synthesis of hybrid trajectories may be found in Reference 2.

For this study of S-IVB disposal from hybrid missions, data was generated using integrated trajectories produced by the Bellcomm Apollo Simulation Program (BCMASP). The launch date was selected so that the distance between earth and moon was about equal to the average distance. The dihedral angle ( $DL_1$ ) between the orbital plane of the moon and the near-earth portion of the outgoing spacecraft orbit was almost zero for a Pacific injection and near the maximum possible value for an Atlantic injection. Both injection types were used in order to bound the dihedral angles characteristic of launching at all possible launch dates and azimuths. Periselene distances of 2 and 3 lunar radii were used, in addition to the nominal Apollo trajectory having a periselene distance of 1.06 lunar radii, corresponding to a 60 n.mi. periselene altitude. The launch time, dihedral angle, earth-moon distance and flight time for these six free return circumlunar trajectories are listed in Table I. In order to derive sensitivities these trajectories were then perturbed by applying a thrust characteristic

of a cold LOX dump through the J-2 engine. The thrust began two hours after TLI and was directed along the negative velocity vector.

## II. RESULTS

The results are shown in Figure 1 for the low dihedral angle case and in Figure 2 for the high dihedral angle case. In each figure the lower set of curves uses the distance from the center of the moon to the S-IVB at periselene as ordinate, and is used to identify those trajectories which impact the moon. The center and upper set of curves use as ordinates the energy and the perigee of the post-encounter trajectory, respectively. Characteristic velocity ( $\Delta V$ ) resulting from the perturbing thrust applied along the velocity vector was used as the abscissa in all cases.

Figure 3 was produced by cross plotting the data of Figures 1 and 2. The two right hand curves are obtained from the lower set of curves, and the remaining curves are obtained from the center and upper set. Using the figures the following observations can be made.

1. The boundary between the lunar impact region and the slingshot region is relatively insensitive to the periselene distance of the unperturbed trajectories ( $R_{pm}$ ).

For low values of the dihedral angle  $DL_1$ , the  $\Delta V$  required is -66 fps for  $R_{pm} = 1.06$ , (nominal Apollo mission) and -61 fps for  $R_{pm} = 3$  lunar radii. For  $DL_1 = 60^\circ$  the  $\Delta V$  required is -45 fps for  $R_{pm} = 1.06$  and -38 fps for  $R_{pm} = 3$  lunar radii. This insensitivity can be explained by dividing the required  $\Delta V$  into two parts, one part ( $\Delta V_1$ ) being the amount required to produce a retrograde grazing orbit and the remainder ( $\Delta V_2$ ) being the amount required to change the orbit further to a posigrade grazing orbit. It is clear that  $\Delta V_1$  increases with increasing periselene distance. However as the energy of the translunar orbit decreases, the sensitivity to a perturbation increases. As a result  $\Delta V_2$  will decrease with increasing periselene distance. Thus the two effects compensate and the total  $\Delta V$  remains relatively constant.

2. The boundary between the slingshot region and the region of geocentric elliptical orbits varies considerably with  $R_{pm}$ . The result is that the range of  $\Delta V$  for producing slingshot trajectories is reduced as  $R_{pm}$  is increased. The extreme case shown in Figure 3 is for  $DL_1 = 60^\circ$  and  $R_{pm} = 3$  lunar radii, where the  $\Delta V$  range which will produce a slingshot trajectory is less than 5 fps.

3. For geocentric elliptical orbits resulting from a  $\Delta V$  in excess of that required for a slingshot, the perigee distance ( $R_{pe}$ ) becomes less as  $R_{pm}$  is increased, and the probability of an earth impact is potentially increased. For  $DL_1 = 60^\circ$  and  $\Delta V = -75$  fps,  $R_{pe} = 20$  earth radii when  $R_{pm} = 1.06$  lunar radii. When  $R_{pm} = 3$  lunar radii,  $R_{pe}$  is reduced to 5 earth radii.

### III. CONCLUSIONS

The accuracy of the maneuvers required for producing slingshot trajectories is increased as periselene distance is increased. In addition, for a given impulse producing an elliptical earth orbit the resulting perigee distance is reduced as the free return periselene distance is increased and hence the probability of earth impact is increased. In general the effect of using a high periselene free return nominal trajectory on slingshot requirements is to increase the sensitivity to errors in execution of the maneuver and lower the nominal impulse requirement.

  
L. P. Gieseler

2013-LPG-srb

Attachments:  
References  
Table I  
Figures

**BELLCOMM. INC.**

REFERENCES

1. L. P. Gieseler, "Disposal of Spent S-IVB Stage on Lunar Missions", Bellcomm Memorandum for File No. B68 12038, dated December 11, 1968.
2. R. A. Bass, "Optimization of Hybrid Trajectories for the Apollo Mission Under a DPS Abort Constraint", Bellcomm Memorandum for File No. B69 02018, dated February 7, 1969.

TABLE I

## CHARACTERISTICS OF UNPERTURBED ORBITS

Launch Date - 22 May 1969 (J.D. = 2440363.5).

Launch Azimuth - 72° for Atlantic and 90° for Pacific Injections

Launch Time (sec.)	Periselene Distance	Dihedral Angle (deg.)	Earth-Moon <sup>1</sup> Dist. (ft.)	Flight Time <sup>2</sup> (hrs)	Injection Type
69781.	1.06 Lunar Radii	0	1.274x10 <sup>9</sup>	74.5	Pacific
69767.	"	0	1.267x10 <sup>9</sup>	82.5	"
69752.	"	0	1.263x10 <sup>9</sup>	88.3	"
13157.	"	59.7	1.284x10 <sup>9</sup>	77.2	Atlantic
15552.	"	60.7	1.275x10 <sup>9</sup>	87.5	"
17411	"	61.1	1.268x10 <sup>9</sup>	95.8	"

<sup>1</sup> When spacecraft is at periselene.<sup>2</sup> Launch to periselene

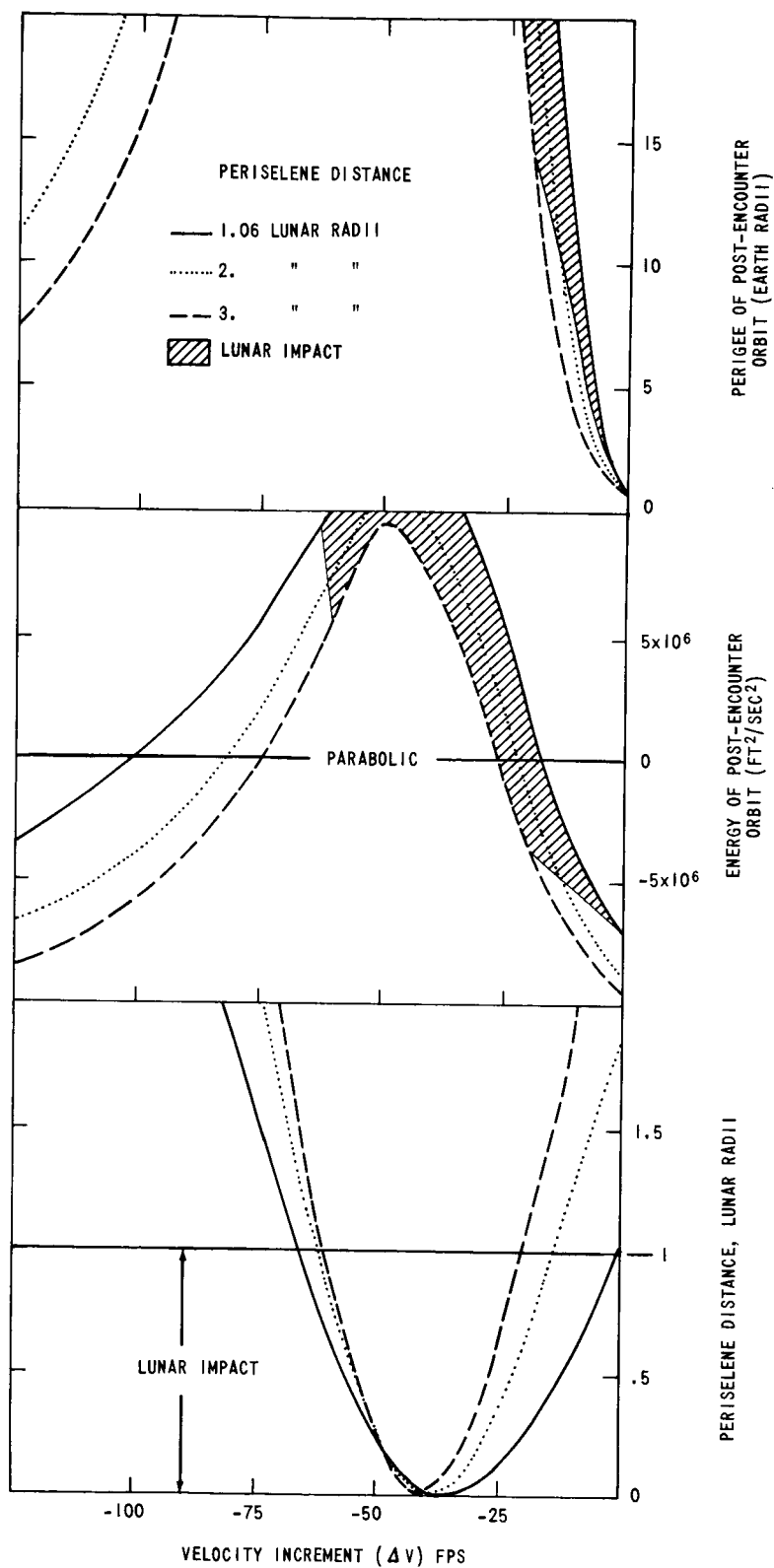


FIGURE 1 - TRAJECTORY CHARACTERISTICS,  $DL_1 = 0^\circ$

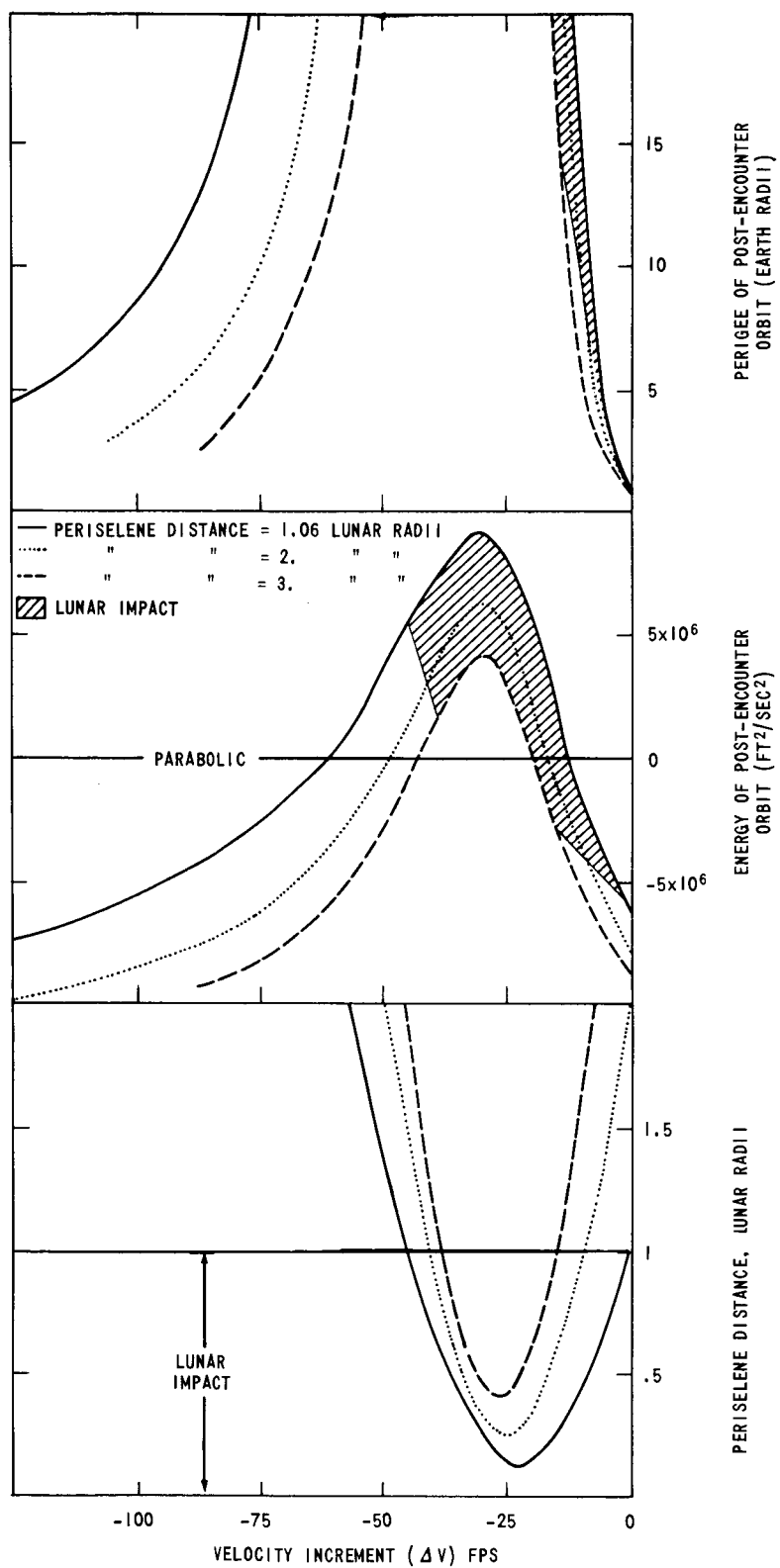


FIGURE 2 - TRAJECTORY CHARACTERISTICS,  $DL_1 = 60^\circ$



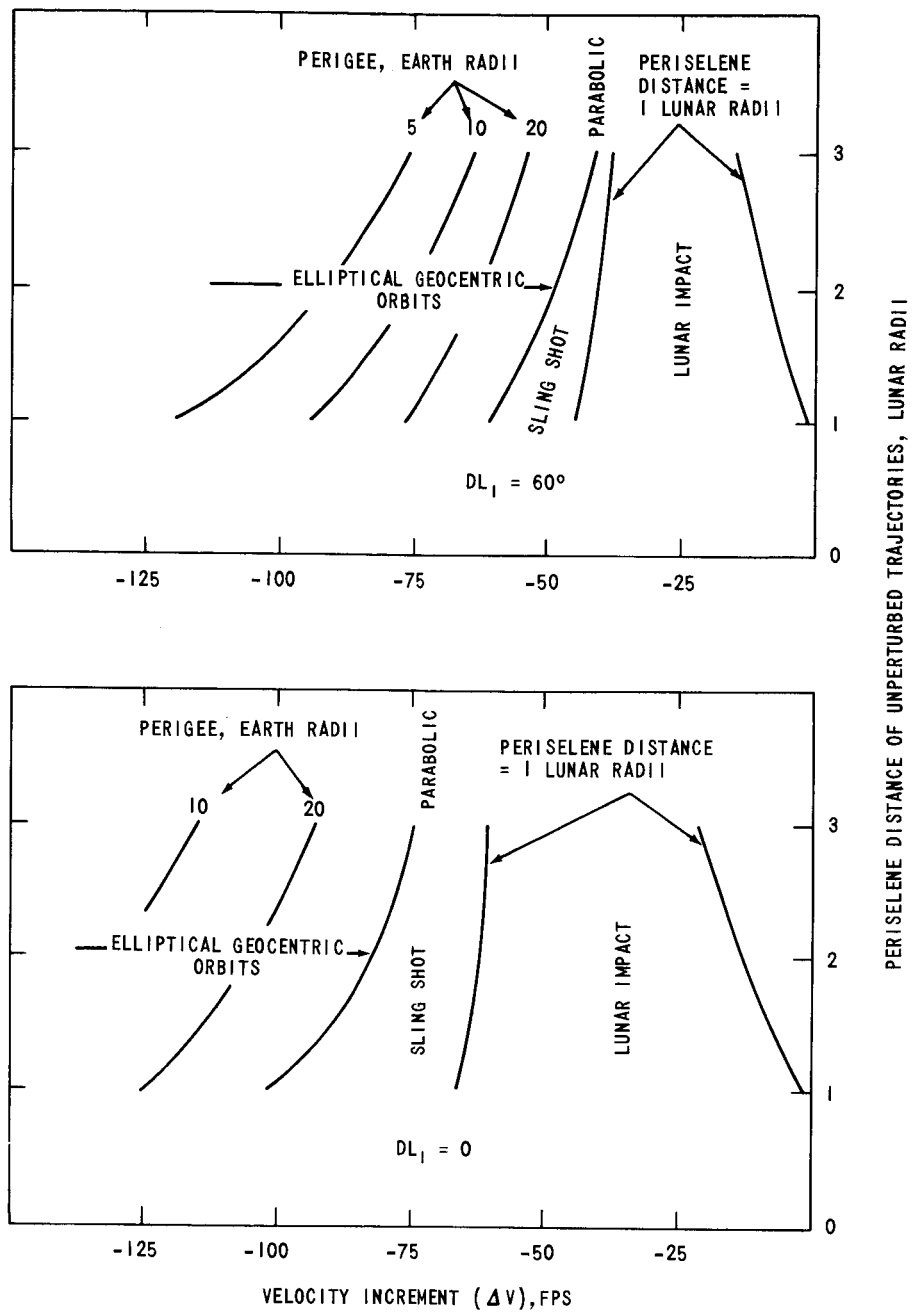


FIGURE 3 - EFFECT OF PERISELENE DISTANCE OF UNPERTURBED TRAJECTORIES